Changing Computing: The Computing Community and DARPA

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Between 1962 and 1986, the Information Processing Techniques Office (IPTO) of the Defense Advanced Research Projects Agency provided significant support for computer science R&D. The design and implementation of the support programs of this office was the responsibility of a small group of computer scientists who emerged from the growing computer science community. Program directors focused on radical technologies, organized programs to develop them, and promoted their use in various settings, with substantial success. A better understanding of the evolution of the Department of Defense's policy for computing R&D can be gained from an analysis of the backgrounds, research experience, interests, and methods of the people engaged to design and implement this policy in IPTO.

Introduction

Narratives about historical developments during the so-called "pioneer period" of electronic digital computing, that is, 1940 to 1960, emphasize the role and desires of military and defense personnel. For example, in Herman Goldstine's memoirs, we learn of his role with the U.S. Army in developing ENIAC and as a project leader in developing the IAS computer [1]. He gives some insight into the nature of certain Army policies toward computer development during and immediately after World War II. Moreover, Nancy Stern refers to many documents written by Army personnel that illustrate the Army's explicit part in the evolution of ENIAC and UNIVAC [2]. The Army formulated policy for their use in specific Army tasks at a time when the full competence of these machines was yet to be discovered. The role of military policies and people are also portrayed in Mina Rees' memoir discussing the Office of Naval Research (ONR) support of computer development in the 1940s and 1950s [3]. When researchers come to examine a larger, more extensive, "military" role in stimulating computing R&D, however, their writings are regularly faceless, motiveless, results-dominated descriptions of developments, even when they focus on the contractors and their products. In these works, the military services and the DOD stand in the background as sources of money, but are not actors in the events. Individuals from DOD are virtually never mentioned, and results are equated with policy intent [4].

Still, results, even from successful developments, are not a policy. Results are also not a program. In addition, the DOD is not a monolithic entity, where programs and policies are agreed to after due deliberation, and promulgated down to lower levels for implementation. In fact, DOD is a collection of fiefdoms of a sort, in which the interests of specific groups are implemented. A group may be involved in tasks where new instrumentation may be useful, as with the Army and ENIAC, or where new defensive systems were required, as with the Air Force and SAGE, or where new weapons systems were required as in the Strategic Defense Initiative [5]. For example, David Allison's study of Navy research activities [6] describes how a group of people in the services, led by a key individual, promotes and pursues the development of a technical system that affects an overall stance of the organization to which the group belongs. Admiral Stanford C. Hopper did this with radio in the early part of this century [7] and William B. McLean did this with the Navy's Sidewinder missile project [8].

One such group is the Defense Advanced Research Projects Agency (DARPA). Recently, a number of authors have written about DARPA's contributions to computing, usually referring to timesharing and networking [9]. Each of these works focuses on the results supposed to be stimulated by military needs. Their interest in DARPA's contributions to computing, through its Information Processing Techniques Office (IPTO), reflects the influence DARPA has had on nonmilitary systems. DARPA/IPTO, hereafter called IPTO, is responsible for the style of computing we have today. IPTO supported the significant research that opened doors to graphics, artificial intelligence, timesharing, networking, VLSI design schemes, and massively parallel processing combined with miniaturization of components. The design and achievement of the IPTO programs were due to the efforts of a small group of computer scientists frustrated with the direction of corporate R&D and its products, who emerged from the growing computer science community. These men–and before the [illegible] there were no women in the group connected with IPTO–focused on radical technologies, organized programs to develop them, and promoted their use in various settings. To understand the evolution of DOD's 1960s policy for computing R&D, we have analyzed the backgrounds, research experience, and interests of the people engaged to design and carry out this policy, and review the methods they used by in establishing programs [10].

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The (Defense) Advanced Research Projects Agency

In response to the Soviet Union's launching of Sputnik, President Dwight David Eisenhower appointed James A. Killian, President of MIT, as a presidential assistant for science and set about to separate the various space and ballistic missile programs to achieve an early successful launch of a satellite [11]. To overcome the rivalry between the services, approval was obtained for the organization of a new agency in the DOD to oversee the development of the United States' space program and to be responsible for separating it into distinct military and civilian components. The new agency's mission was soon to be more broadly designed. It came to play a very significant role in further R&D support for computing.

The new agency, the Advanced Research Projects Agency (ARPA), was thus an effort to rationalize research and development at different levels within the DOD, and to stimulate new elements in frontier technology development in response to Sputnik. ARPA later became Defense ARPA, but in 1993 it was renamed ARPA. DARPA's mission throughout its history was to prevent major technological surprises like Sputnik, and to serve as the mechanism for high risk R&D where the technology was in its early stages and where the technical opportunities transcended military service roles and mission [12]. In the areas like space, nuclear test detection, missiles, satellites, and materials, DARPA's objectives were to maintain technical vigilance and provide a quick response to technical developments outside the country.

After DARPA completed the space program task, it served as a source of research support for high-risk/high-payoff, multiservice-oriented activities. It has no research laboratories of its own. Instead, it has supported R&D programs in organizations outside the DOD and participated in these R&D efforts through close cooperation between DARPA personnel and members of the research organizations [13]. While contributing substantially to the DOD mission throughout its history, DARPA has also developed enabling technologies useful well beyond military systems [14].

DARPA's success resulted from the nature and range of its support programs and its management style. Its programs focused on R&D at the frontier of high-technology systems for defense. Consider the range of its programs in the 1960s: ballistic missile defense, nuclear test detection systems, special programs for use in the Vietnam conflict, materials sciences, and information processing. When DARPA directors referred to military and political success, they usually cited accomplishments in the nuclear monitoring and ballistic missile programs. When they wished to call attention to the contributions to civilian society, they described the accomplishments of the information processing and materials science programs. Indeed, the public reputation of DARPA concerning its programmatic prowess comes almost entirely from the latter two programs [15].

The other important factor in DARPA's success is its management style. In nearly all offices and programs, the agency had a lean administrative structure, extensive field contact, fast turnaround times for proposals, a record of supporting high-risk concepts and development projects, exceedingly capable staff, a history of block grants and multiple-year contracts, a proposal evaluation mechanism that was largely internal rather than through peer review, and in some offices a consistent ability to fund ideas that have had major effects in society.

This management style was a combination of the military approach to R&D support and the talents and experience of the civilian directors of the agency. DOD officers are used to supporting R&D through large contracts, carefully monitored by DOD personnel who frequently participate in the determination of the requirements of the contract, and carefully converging projects meant to be coordinated into larger systems development. To direct projects of this sort, Secretaries of Defense chose men with a mix of experience in industry and government, along with advanced training in higher education in a technical area. (See Table 1 for a list of DARPA directors, their dates of tenure, and educational backgrounds.)

TABLE 1. DARPA DIRECTORS (1958 - 1987)

Director	Term	Educational Background
Roy W. Johnson	2/58 - 11/59	BA University of Michigan, 1927
Austin W. Betts	12/59 - 1/61	MS MIT, Civil Eng., 1938
Jack P. Ruina	2/61 - 9/63	PhD Polytechnic Institute of Brooklyn, Electrical Eng., 1951
Robert L. Sproull	9/63 - 6/65	PhD Cornell, Physics, 1943
Charles M. Herzfeld	6/65 - 3/67	PhD University of Chicago, Physics, 1951
Eberhardt Rechtin	11/67 - 1/71	PhD California Institute of Technology, Industrial Eng., 1950
Stephen J. Lukasik	1/71 - 12/74	PhD MIT, Physics, 1956
George H. Heilmeier	1/75 - 12/77	PhD Princeton, Electrical Eng., 1962
Robert Fossum	12/77 - 7/81	PhD Oregon State Univ., Math. Statistics, 1969
Robert S. Cooper	7/81 - 7/85	Sc.D. MIT, Electrical Eng., 1963
Robert C. Duncan	7/85 - 4/87	Sc.D. MIT, Instrumentation, 1960

Several developments, events, and explorations shaped the DOD response to a perceived need for more R&D in information processing. First, a recognition inside DOD of the shortcomings of command and control systems was perhaps the most important stimulus. While concerns for command and control problems existed throughout military history, it was only in the late 1950s that the area received general recognition and the term "command and control" became common [16]. By 1960 the DOD recognized that it required timely analysis of large amounts of information. Command and control in rapidly changing military environments requires the collection of data about the environment, planning for options, decisions, and dissemination of the decisions [17]. Control over as much strategic information as possible would improve command decisions. Computing technology could control large amounts of information and present it in effective ways to aid decision making. Weapon systems and missile guidance systems used computers as the central control element. Earlier military concern with processing information and employing the results in command decisions focused on the problems of human relations

[18]. In the early 1960s, the focus shifted to an examination of the informational aspects, and computer use in military systems expanded [19]. Military interest in computing technology was heightened by the merging of information technology, command techniques in the new military weapons environment, and missile control systems.

In early 1960, DARPA contracted with the Institute for Defense Analysis (IDA) to do a survey of the information sciences and their relevance to defense concerns. The study, led by F. H. Tyaack, noted five critical DOD problems related to information science:

- pattern recognition and formation of concepts out of data,
- decision-making,
- communications,
- control, and
- information storage and retrieval, data handling, and data processing [20].

Research activities already supported by agencies of the DOD ranged from mainline applications of psychology, the social sciences, and biology to specific projects in encoding of basic information, self-organizing systems, and heuristic and adaptive computers. There was no plan behind these disparate activities.

Second, the Kennedy Administration arrived in the White House in 1961 with concerns about defense and a desire for new programs. Eugene Fubini became the Director of Defense Research & Engineering (DDR&E) and Jack Ruina became DARPA director. These two men carried out the new administration's program for R&D on new defense systems. In March 1961, President Kennedy, in a special message to Congress on defense spending, called for the improvement of command and control systems to make them "more flexible, more selective, more deliberate, better protected, and under ultimate civilian authority at all times" [21]. In June 1961, Fubini's office assigned a Command and Control Project to DARPA. By the end of June, Ruina assigned IDA the DARPA task of a "Digital Computer Application Study" with the goal of studying how to apply computing to command and control problems [22]. One of the report's recommendations was to expand research in "potentially fruitful" areas such as problem (or algorithm) "formulation, analysis and programming," and communication between machines and their users. The report called for basic research in pattern recognition, concept formulation and recognition, problem-solving, learning, and decision making, and research directed toward improving computer dependability.

Third, in companies like MITRE and Systems Development Corporation (SDC) there was a growing interest in information-processing research, which led to proposals to DOD for support. As a start in carrying out the recommendations of the IDA study and in response to these proposals, DARPA, in August 1961, gave SDC in Santa Monica, California, a multimillion dollar contract to pursue research on the conceptual aspects of command and control systems. While a division of the RAND Corporation, SDC had been responsible for operator training and software development for the Semi-Automatic Ground Eovironment (SAGE) air defense system of the 1950s. In 1957, SDC became a separate organization. It submitted a proposal to DARPA to establish a command and control laboratory using the SAGE Q-32 computer that had been part of a canceled program for SAGE Super Combat Centers in November 1960 [23]. SDC's proposal included "conceptual and operational studies: surveys of related experiences and plans by military commands; research in organization of command, information flow, and system description; modeling and simulation of different command networks, and operation of a command laboratory for experiments and verification" [24]. The principal justification for the SDC command and control research program in the DARPA program plan was that "automation is threatening to usurp the commander's role, stultify command organization and response, and make more difficult the modernization and exercise of an integrated, strong, selective national command" [25]. DARPA funded this project with an initial $6 million contract, and included one of the SAGE Q-32 computers.

Since the Q-32, typical of all computing machines of the period, did not come with software, much of the research to be done was in software and applications systems. In 1960, for many well-defined problems of interest to large organizations–accounting, inventory, logistics–existing computing methods were adequate. However, a range of poorly-defined new scientific and engineering problems, namely those being investigated by university research departments, the space and missile defense programs, the military's command and control proponents, and the nuclear weapons program, stretched the capability and capacity of the installed computer base to the limit. Computing, as it was practiced around 1960, was not equal to the management of large amounts of data in a rapidly changing context. There were guideposts, however.

The SAGE system had shown what was possible in treating large amounts of changing data with faster and more capable computing, but not much progress had been made by 1960 in exploiting these possibilities. Most computing R&D still focused on the problem of massive data reduction for business or scientific research, where large amounts of processing were done to yield repetitive or individual results. For these, new large machines were under development; oew languages for greater efficiency were in design; better data input and output and display techniques were reaching the market. Advances in computing in universities, where the system was considered a specialized scientific instrument, differed from those in companies, where the system was considered as a large business machine. More to the point, these developments had small effect on computer use in command and control operations in the late 1950s. Bolder, more imaginative steps were oeeded. Many needed greater capability to interact with each other to gather relevant information, solve problems, anticipate data requirements, communicate effectively across distances, present information visually, and do all this automatically. These steps required both imaginative individuals and substantial funding.

Instead of continuing to develop specific computing machines, as the DOD had done io the 1940s and 1950s, DARPA officials generalized their interest in computing into the Information Processing Techniques Office (IPTO). In 1962, IPTO became the newest, and perhaps the most significant, of the DOD's activities in computing.

The Information Processing Techniques Office

From its fouoding in 1962 to the mid 1980s, DARPA's IPTO provided substantial research support for bold and imaginative development of computer science and eogineering [26]. It did so by exploiting the partnership between the defense and academic communities. When IPTO began in 1962, computing was a group of loosely related activities in theory, programming, language development, artificial intelligence, systems architecture, etc., which had been pursued vigorously in the 1950s. Research to advance architectural systems through design of new logic circuitry and enhanced connections among component systems, to improve numerical techniques for the solution of problems, to introduce new input/output designs, and to develop new ideas for more efficient use of the entire computer system had made rapid advances in the 1950s. Systems became more reliable, more efficient, and less costly. Computer companies introduced many models for business and for scientific computing.

Toward the end of the 1950s, some researchers, however, were starting to view computers as partners in creative thinking, to explore the interaction between people and computers, to create artificially intelligent systems, and to develop natural language and machine translation processing systems. These university researchers were interested in smarter, more flexible, and more interactive systems.

IPTO invested in selected problems posed by these researchers to provide *more capable, flexible, intelligent, and interactive computer systems* changing the content *and* style of computing through timesharing, networking, graphics, artificial iotelligence, parallel architectures, and very large scale integration (VLSI) components. This new style of computing was intended for use in computer science research and ultimately in military systems, and it was effectively used in both.

IPTO set ambitious objectives for new computing technology. To achieve these objectives, IPTO employed a dynamic, highly-effective, well-respected, and insightful approach to R&D funding. IPTO directors and program managers took advantage of an amalgam of approaches used by other military agencies in the 1950s and some new ones designed for the special circumstances in DARPA. Among them were fast tumarouod times for project approval and extensive personal initiative by program personnel. The strategy applied to program development and change remained consistent over time in spite of, maybe because of, all the changes in staffing and funding.

At the outset, IPTO began research projects to investigate displaying images, memory partitioning, paging, symbolic processing (to improve the machine's capacity to assist humans), and linking of machines to share resources. Attempts were made to increase the capability of machines through natural language communication techniques, understanding of human problem solving, and new graphical interfacing techniques. During the 1960s, IPTO and its contractors made substantial progress toward more flexible and interactive computer systems, fulfilling the promise of the SAGE system. For example by the end of its first decade, timesharing was part of every IPTO-sponsored center and the ARPANET was emerging as a functioning communication medium. When IPTO set out to develop a network for conoecting IPTO-supported sites, the prevailing technology for networking was unreliable, slow and expensive. IPTO launched out in a new direction, following a typical military pattern for R&D, the result of which was a new generic technology: packet switching. It was only in the 1980s that some of IPTO's objectives had clearly been reached through the development of an entirely oew technological approach, such as networking by using packet switching.

IPTO had significant budgets to expend on programmatic objectives because of its place within the DOD. High-risk projects often require long-term support. IPTO's budget made it possible to sustain these projects.

DARPA chose managers with foresight, experience, and capability, and gave them substantial freedom to design and manage their programs. Often the difference between programmatic success and failure came down to one person, and how he or she managed a program. The fact that IPTO recruited capable and technically able members of the research community and allowed these people an unusual amount of freedom to promote research as *they* saw fit, seek advice as *they* felt the need, and manage the office as *they* thought the program required, was the deciding element in IPTO's success [27].

Computing, as it was practiced around 1960, was not equal to the management of large amounts of data in a rapidly changing context.

The people who directed and managed IPTO programs were visionary and insightful about the needs of the research community. First, they evaluated the potential and needs of the computing research community, not, as in previous assessments of computing by other research agencies, such as NSF, to enhance the computer as a tool in scientific and engineering research but to achieve specific objectives in software for connectivity, display, decision aids, and increased capability. Then they moved the results of research out into the industrial and military sectors, which affected computing generally.

Staffing IPTO: Office Directors

When Eugene Fubini and Jack Ruina sought an inaugural director for IPTO, they turned to the Cambridge, Massachusetts, scientific and technical community. Their choice was based on discoveries and inventions of workers in the laboratories of MIT and Harvard and the many companies they spawned, and on an association with the military community that some historians have called the military-industrial complex in the United States. Forged mostly in the MIT Radiatioo Laboratory of wartime Cambridge, this community took a leading role in the production of defense systems for the Cold War world, with consequences for MIT, the New England economy, the nation, and the world [28].

The community in the 1950s assembled various venues, e.g., the M.I.T. Servomechanism Laboratory that produced Whirlwind, the M.I.T. Research Laboratory of Electronics that led in information theory and many new electronic devices, the Draper Instrumeotation laboratory where many missile guidance systems were designed, and the Aiken Computational Laboratory at Harvard.

Members of these laboratories founded a new set of organizations to act as the intermediaries between the basic researchers and the industries that would build new defense systems: Lincoln Laboratory, Bolt, Beranek and Newman (BBN), MITRE Corporation, and Air Force Cambridge Research Laboratories. Defense companies formed the third part of the Cambridge community of

interest –Raytheon, General Radio, Honeywell, and Digital Equipment Corporation.

As illustrated below, four of the six IPTO directors discussed in this article acquired experience in organizations at the middle level of this pyramid, the systems integrators like BBN and MITRE. A fifth came from another part of the defense community–the aerospace industry, and the sixth from the military. Thus, their experience prepared them for the kind of mission given to IPTO: to stimulate or find the new ideas that could quickly be integrated into new defense systems, in the case of IPTO, in command and control systems. IPTO never lost sight of its primary mission to support the objectives of the DOD.

J.C.R. Licklider, whom Fubini and Ruina chose to lead DARPA's new office, had attended Washington University where he earned an AB degree in 1937 with majors in physics, mathematics, and psychology, and an AM degree in psychology in 1938. In 1942 he received a PhD in psychology from the University of Rochester. In many ways, Licklider was more a product of the Cambridge community than of the institutions from which he received his training. During World War II he was a research associate and research fellow in the Psycho-Acoustic Laboratory at Harvard University, working on defense projects. After the war he stayed at Harvard for a few years and then joined the Psychology Department of MIT as an associate professor. During the 1950s, Licklider was an Associate Professor in the Electrical Engineering Department at MIT, and a member of the Research Laboratory of Electronics and the Acoustics Laboratory. He participated in the Project Charles study of air defense that led to the establishment of Lincoln Laboratory, and was a group leader at the newly established laboratory. In addition, he served as a consultant to local laboratories and companies, served on the Air Force Scientific Advisory Board, and consulted directly with the DOD. In 1957, he became a vice president at Bolt, Beranek and Newman (BBN), a company engaged in studies in acoustics, psychoacoustics, human-machine systems, and information systems.

J.C.R. Licklider.
Photo courtesy of the MIT Museum

A quiet, modest, self-possessed man, Licklider became a good research leader. He possessed the ability to design research projects with expansive objectives, such as the BBN project on human-machine research sponsored by the Air Force Office of Scientific Research. This research primarily involved study of the domain and parameters of systems theory, particularly human factors aspects in complex human-human and human-machine systems [29]. A major part of the research related to the interaction of complex systems, and their simulation by computer. In another part of this research, which was reflected in his later design of programs at IPTO, he divided human operator and human-machine system functions into their elementary operations [30]. Licklider listened well, was ready to help young researchers by offering insight into the limitations of a concept and how it could be expanded, and understood how to enhance a project's results so it became part of a larger objective. He demanded excellence of himself and of those around him.

During his conversation with Fubini and Ruina, Licklider asserted his belief that the problems of command and control were primarily problems of human-computer interaction. Fubini and Ruina enthusiastically agreed [31]. Licklider had published a program for improving human capabilities using computers [32]. In effect the computer would help the human to think. He identified several research questions in computer memory programming, natural and computer language compatibility, displays, and speech recognition. Through the 1960 IDA survey discussed above, the DOD and DARPA had come to recognize that these areas should be attended to in order to advance command and control systems. The fact that these were all active research areas in the Cambridge community meant a neat fit between academic research interests there and system interests of the defense community. IPTO was the right place for setting up programs to achieve the vision Licklider described in this 1960 paper. Ruina offered Licklider the position, and he started at DARPA in October 1962, although he was involved in assessment of projects in the preceding few months [33].

Licklider instilled a criterion of excellence, a vision of the future of computing, a focus on a few centers of activity, and a concern for contributing to computing to serve both the military mission of DOD and society generally into IPTO program management. Shortly before he joined DARPA in 1962, Licklider wrote a letter to Charles Hutchinson, the director of the Air Force Office for Scientific Research (AFOSR), in which he noted that his main objective would be "to spend the Government's money very carefully and very wisely." Expenditures would have to satisfy at least three criteria:

- The research must be excellent research as evaluated from a scientific or technical point of view.
- The research must offer a good prospect of solving problems that are of interest to the Department of Defense.
- The various sponsored efforts must fit together into one or more coherent programs that will provide a mechanism not only for the execution of the research, but also for bringing to bear upon the operations in the Defense Department the applicable results of the research *and* the knowledge and methods that have been developed in the fields in which the research is carried out [34].

Contrary to Hutchinson's advice to commit programs "in a hurry," Licklider felt it to be "of paramount importance to organize a coherent program and not to act until there has been an opportunity for careful investigation and deliberation (by staff as well as by advisors)" [35]. Licklider set up twin poles of the IPTO program that his successors followed throughout IPTO's history: a convergence of objectives between academic and military interests and a coherence in the initiated programs over time. To achieve these objectives, Licklider followed the DARPA style and adopted a lean administrative structure for IPTO. In fact, he managed two programs simultaneously, IPTO and the Behavioral Sciences Office with a combined budget of $11,000,000, with the help of one secretary!

The elements of Licklider's approach to funding by IPTO were passed on through the next decades from office director to office director, and from program manager to program manager. Taylor, the third IPTO director, had read Licklider's "Man-Computer Symbiosis" paper well before he went to DARPA and "heartily subscribed" to its goals. When he joined IPTO, he assessed the IPTO programs, but as an adherent to the Licklider philosophy, he saw little reason to change direction after he assumed the directorship. Licklider's philosophy was firmly established:

> What we were trying to do, on the one hand, was to select research problems that were ripe enough to have some hope of making progress on them, but on the other hand, to select them with the notion that if we succeeded it would make an order of magnitude difference between the way in which business was done then, versus what this new research finding might permit.... We were explicitly looking for things which, if they could succeed, would really be a large step beyond what technology could then permit [36].

Taylor interpreted IPTO's role as filling a niche that "other agencies would be unable to fill because of their limited budgets." Believing that individual researchers were "already pretty well covered" led IPTO to focus on funding groups in institutions rather than the research projects of individuals, as did NSF and NIH [37].

How was this philosophy passed on? When Ivan Sutherland joined IPTO, Licklider was still office director. The two men shared the work of the office so that Sutherland could more easily make the transition. Taylor succeeded Sutherland after a similar period as apprentice director. Lawrence Roberts worked closely with Robert Taylor toward the end of Taylor's directorship in a sort of apprenticeship. In the early 1970s, a deputy director position was added to the office, and this post became a launching pad to the directorship. Both David Russell and Robert Kahn were deputy directors before they assumed the directorship.

Such a similarity of philosophical approach was further enhanced because choosing a successor was the IPTO director's responsibility. During one of Licklider's many visits to MIT while he was IPTO director, he learned of the work of the young superstar Ivan Sutherland. Sutherland, then a graduate student at MIT working in graphics, was invited to the first conference sponsored by IPTO on interactive graphics. This conference was Licklider's first encounter with Sutherland. During the conference Sutherland asked, "the kind of question that indicated that this unknown young fellow might have something interesting to say to this high-powered assemblage." Using an IPTO prerogative of reorganizing conference programs to take advantage of new ideas and information, Licklider asked Sutherland to give a presentation the next day. The presentation was a great success and impressed Licklider. When Licklider was preparing to leave IPTO in 1964, he recommended Sutherland to replace him. Licklider had some reservations because of Sutherland's youth, but Robert Sproull, Ruina's successor as DARPA director, saw no problem, "if Sutherland was really as bright as he was said to be"[38].

Ivan Sutherland

Robert Taylor

At the time he joined IPTO, Sutherland was 26 years old, already serious and scholarly. He attended Carnegie Mellon University (CMU) and Caltech before receiving his PhD degree in electrical engineering from MIT in 1963 where he worked with Claude Shannon, Wesley Clark, and Marvin Minsky. While at Lincoln, Sutherland developed Sketchpad, the first interactive graphics system.

When Sutherland finished his degree in 1963, he served a stint in the Army, where he was assigned to an Army project on side-looking radar at the University of Michigan. Then he was reassigned to the National Security Agency (NSA) for work on a display system. During this project he was asked to visit DARPA and discuss the possibility of assuming the IPTO directorship. "I felt at the time that it was probably too large a job for me to undertake at that age. I initially said no, and then thought about it for another six weeks. They twisted my arm a little harder, and I agreed to go" [39].

Hardworking and private, Sutherland adopted Licklider's approach to contractor selection,

> the caliber of people that you want to do research at that level are people who have ideas that you can either back or not, but they are quite difficult to influence. In the research business, the researchers themselves, I think, know what is important. What they will work on is what they think is interesting and important.... Good research comes from the researchers themselves rather than from the outside [40].

Once Sutherland convinced himself that a research project was worth funding all he needed to do was to convince his superior that something "was sensible to do." While Sutherland needed to prepare justifications for his recommendations, "I always felt that the principal hurdle to get through was to convince the DARPA director that it was a sensible task." The two DARPA directors he had to "convince" during his tenure were Robert Sproull and Charles Herzfeld, both of whom understood the possible value of IPTO results for other programs in DARPA [41].

Sutherland recruited as his deputy and possible successor Robert Taylor, a program officer from the National Aeronautics and Space Administration (NASA). Taylor was a native of Texas and

educated at the University of Texas at Austin. During research on his master's degree, he worked with a group trying to build a model of the functioning of the auditory nervous system for the cases of sound localization and masking of signal against noise background [42]. The group was doing both basic and applied research in acoustics. During his work at Texas, Taylor learned of Licklider's early work. In 1960, he took a position as a systems design engineer at the Martin Company, now Martin Marietta, in Florida; he left the following year to work in human-machine systems research at ACF Electronics in Maryland and moved in 1962 to NASA's Office of Research and Technology that funded some work in computing [43]. Taylor was an ebullient and far-sighted individual, as evidenced in the many innovative projects he managed over the years [44].

Taylor and Licklider met when Licklider organized meetings of an informal committee of government program officers from the Army Research Office, the AFOSR, ONR, NIH, NASA, and NSF, all of which funded computing activities [45]. Members kept each other informed about the projects they were funding to avoid duplication. "We would discuss what was important, what was current, and what was going on. It was a wonderful way of getting information flow between the agencies" [46].

While Taylor served essentially as deputy director of IPTO, he and Sutherland shared all tasks. "We didn't divide up the work in any sense at all" [47]. Taylor served in this capacity for some 18 months. When Sutherland left in mid-1966, Taylor assumed the position of office director. When Taylor became director, the office had several large contracts–Project MAC at MIT, ILLIAC IV at the University of Illinois and Burroughs, and SDC–along with some smaller ones in timesharing, artificial intelligence, graphics, and programming. Little maneuvering room existed. But as Kahn later said of him, Taylor "had incredibly good taste [technically] and intuition" [48]. Taylor saw an opportunity to develop networking, and this became the major focus added to the others during his tenure as director.

The next director, Lawrence Roberts, was an officemate of Sutherland while the two were graduate students at MIT, where Roberts cut his computing teeth on the TX-0 and TX-2. When the TX-0, the first transistorized machine, was moved from Lincoln to MIT, Roberts, an assistant in the computation center, used it to teach himself the basics of computer design and operation. He wrote a program that recognized handwritten characters based on a neural net design. His dissertation under Peter Elias, an M.I.T. professor specializing in information theory, dealt with computer perception of three-dimensional solids. He worked as a research assistant in the Research Laboratory of Electronics (RLE) and as a staff associate at Lincoln Laboratory where he developed an operating system and compiler for the TX-2 at Lincoln.

Roberts was thus well known to IPTO personnel before Taylor recruited him in late 1966 to manage a networking program. Conversations with Licklider and others in 1964 at the Homestead conference convinced Roberts that "the next thing, really, was making all of this incompatible work compatible with some sort of networking." Following the meeting, Roberts began "to investigate how computers could work with each other and how to do inter-computer communications and computing" [49].

At first, Roberts was reluctant to leave Lincoln for IPTO, but as management of DARPA and Lincoln became increasingly insistent that he do so, he changed his mind:

> I was coming to the point of view... that this research [the computing group at Lincoln] that we were doing was not getting to the rest of the world; that no matter what we did we could not get it known. It was part of that concept of building the network: how do we build a network to get it distributed so that people could use whatever was done? I was feeling that we were now probably 20 years ahead of what anybody was going to use and still there was no path for them to pick up.... So I really was feeling a pull towards getting more into the real world, rather than remain in that sort of ivory tower.... In the course of all these discussions, people made me aware that I would than be exposed to a lot more, because everybody comes to ARPA [50].

Accomplished in graphics and networking, fully aware of the benefits of timesharing and artificial intelligence, the dynamic and articulate Roberts was an ideal director of IPTO. After Roberts joined IPTO, Taylor eventually increased the range of Roberts' activities in the office until Roberts could handle all aspects of the office and Taylor was ready to leave [51].

In retrospect, the 1960s could be considered IPTO's glory years. Licklider had come to IPTO in 1962 with a vision of how to increase human-computer interaction and established a program of breadth and depth to realize this vision. His successors, Sutherland, Taylor, and Roberts, all subscribed to this vision and continued to promote it. When examined from the perspective of contributions to computing research, the directorships of Licklider through Roberts were successful ventures in government funding of R&D.

By the end of Roberts tenure in 1973, DARPA, IPTO, and the entire DOD had changed, and computer science had matured, so sustaining the philosophy was more difficult. Heightened Congressional interest in specific program content, increased industrial influence in DOD, White House discontent with various DOD policies, and the public attitude toward the military had changed from admiration to skepticism. The glorious days of the 1960s of space, missile, and Great Society programs were over, and the grim realities of the Vietnam war affected all planning and funding. These all contributed to an aversion of many members of the computing community to joining IPTO. A successor had not been [illegible] before Roberts le[illegible] 1973. Stephen L[illegible] DARPA directo[illegible] Licklider to [illegible] IPTO for another [illegible] director. Licklider [illegible] in January 1974.

David Russell.

Allan Blue, a [illegible] officer in IPTO [illegible] 1967 to 1977, co[illegible] his perceptions of ch[illegible] at IPTO in these years [illegible] the political and budgetary climates. He believed that, because of these changes, the leadership style needed for effective operation in the early days was no longer necessary. At first, the aim was to find talented people, provide ample money for programs, and expect good results from managers. By 1977 Blue believed that, "trying to do just good, basic research for the joy of it was extremely difficult, if not impossible, to get through the budget process" [52]. According to Blue, directed research became the standard and relevance tests were applied. Patrick Winston, director of the MIT Artificial Intelligence Laboratory, shared Blue's evaluation:

> In recent years [the 1980s], DARPA has not funded entire laboratories as centers of excellence, but has, instead, supported specific projects within laboratories.... During the 1970s ...there was tremendous pressure to produce stuff that looked like it had a short applications horizon... the mid 1970s were days in which you had to find a way of explaining the work in applications terms. It wasn't enough to study reasoning; you had to talk about how it might be applied to ship maintenance or something....

Winston encouraged some of his colleagues in the MIT AI Laboratory to design some projects that would meet these new IPTO criteria.

> I was seeking to find intersections between what the laboratory was doing and what DARPA either was interested in or could be persuaded to be interested in. So in some cases, it was a matter of pointing out the potential applications of a piece of work [53].

The DDR&E director's response to congressional concerns was largely responsible for this changing emphasis in DARPA and IPTO R&D support programs when Licklider served a second term as IPTO director, from early 1974 through mid 1975.

After a stormy second term, Licklider was succeeded not by a member of the computing community, but by David Russell. Russell received a PhD in physics from Tulane University in 1968 for a study of the energy levels of the element erbium using the Mossbauer effect technique. He served in the Army in Vietnam, and at DARPA's Nuclear Monitoring Office. DARPA director George Heilmeier transferred Colonel Russell to IPTO in 1974 to serve as deputy director under Licklider, and the following year Russell succeeded Licklider as director.

The next office director was Robert Kahn, a believer in social engineering in the widest possible sense, who expanded access to the networks to the greatest number of users most effectively. He joined IPTO as a program manager in 1972. His PhD degree in electrical engineering from Princeton in 1964 was earned with a dissertation on sampling and representation of signals using applied mathematics and theory, and he was also part of the Bell Laboratories traffic group. The group studied queuing theory, analysis of switching performance, and global engineering of the Bell System. After graduation Kahn joined the MIT faculty as an assistant professor of Electrical Engineering in the Research Laboratory of Electronics (RLE). In 1966, Kahn decided to spend a leave at Bolt, Beranek and Newman, Inc. [54].

Saul Amarel.

Immediately upon his arrival at BBN, Kahn began working on problems of networking computers. "I was largely involved in design of various techniques for networking, error control techniques, flow control techniques, and the like." Early in 1967 Kahn wrote a letter to Lawrence Roberts suggesting networking might be of interest to IPTO. Roberts invited him to Washington to talk about his ideas: "I found out at that point that [Roberts]

In retrospect, the 1960s could be considered IPTO's glory years.

was actually interested in creating this net. Having been a mathematician or theoretician, it really had not occurred to me at that point that I might ever get involved in something that could become real!" Kahn helped design specifications for what eventually became the ARPANET, and played a role in BBN's accomplishment of the contract for the detailed design and construction of the first four ARPANET nodes [55]. Kahn also arranged for a public demonstration of the ARPANET. Kahn and Steve Levy were planning a new commercial initiative for BBN–Telenet–to exploit the packet-switching technology developed for ARPANET. Levy became its first president. When Roberts left IPTO in 1973, he became Telenet's second president. A few months after the successful demonstration, Kahn joined IPTO as a technical program manager with perhaps the greatest background knowledge of any person who joined the office. The development of the ARPANET put him and his coworkers at BBN in touch with virtually every one of IPTO's contractors, with whom he continued to work for the next seven years. In 1979, Kahn became IPTO director. He engineered a fivefold increase in the office budget, seizing opportunities presented by the Reagan Administration's defense buildup of the 1980s [56].

Kahn was succeeded as director of IPTO by Saul Amarel. Amarel's experience in both industry and academia, and his research in artificial intelligence, complemented IPTO's increased exploitation of AI in the 1980s defense program. He had obtained his degree from Columbia University in electrical engineering in 1955, and he spent the next 10 years directing the Computer Theory Research Group at RCA Laboratories. Amarel focused on machine problem solving: theorem proving in the propositional calculus, knowledge representation issues, and theory formation. In 1969 he moved to Rutgers and organized the computer science department there. While on sabbatical in 1985 with Herbert Simon at CMU, Amarel agreed to head IPTO [57]. In the DARPA atmosphere of the 1980s, his success was limited by the expansion of other offices that wanted to cash in on the enlarged computing program. IPTO was restructured in 1986 as the Information Sciences and Technology Office (ISTO).

IPTO capitalized on the expansive vision of these men. All had emerged in computer science as it was flexing its muscles and were imbued with its limitless possibilities. For Licklider and his successors, the pursuit of these visions became almost a missionary activity [58]. Their DOD activities are elegant examples of the partnership between the military and the civilian technical community.

directors, leaving the management of IPTO to Licklider and his successors. DARPA directors were content that the program was appropriate to DOD needs and well directed [59]. Therefore, the early program evolved in directions related to each of the IPTO directors' strengths.

IPTO's research support focused on a few centers: Carnegie Mellon University (CMU), MIT, Stanford, UCLA, Illinois, Utah, Caltech, The University of Southern California, Berkeley, and Rutgers. The number of centers was a small percentage of all the institutions engaged in R&D for computer science and engineering.

Staffing IPTO: Program Managers

By the late 1960s, program managers were hired to manage specific programs within the office, with the major selection criterion being their technical competence. In 1972, there were five professionals in IPTO-Roberts, Kahn, Stephen Crocker, Bruce Dolan, and John Perry. Allan Blue managed the business aspects of IPTO. In the second half of the 1970s, this number continued to increase, although the comings and goings make it difficult to cite a stable number at any given time. David Carlstrom managed the artificial intelligence program from 1974 to 1978. Vinton Cerf assumed responsibility for the interconnection of networks in 1976 and stayed until 1982. Floyd Hollister managed the Advanced Command and Control Architectural Testbed and its related programs from 1976 to 1978. Duane Adams arrived at IPTO in late 1977, worked with programs in packet speech and VLSI, among others, and left in mid-1983. Robert Engelmore came to IPTO in March 1979 and specialized in intelligent systems at IPTO until mid 1981. Cerf had a PhD degree from UCLA; Hollister had a degree from the U.S. Navy Postgraduate School; Engelmore received his PhD from CMU, and Adams earned his from Stanford. Each man was comparatively young when he joined IPTO.

Ronald B. Ohlander, a PhD in artificial intelligence (AI) from Georgia Institute of Technology, managed AI programs from 1981 to1985. Paul Losleben arrived at IPTO in mid-1981 to manage the VLSI program and continued into the Strategic Computing era, leaving in late 1985. Stephen Squires came to IPTO in 1983 to work in software and architectures for the Strategic Computing Program and is still with DARPA [60]. Robert Simpson, Jr., a PhD in AI from CMU and an MBA from the University of Oklahoma, came to IPTO in 1985 to manage a part of the growing artificial intelligence program under the Strategic Computing Program and left in 1990. Ohlander and Simpson had military experience in the Air Force and Navy, respectively [61]. Squires had an electrical engineering degree from Drexel University and spent some time at Princeton, Harvard, and the National Security Agency (NSA) before joining IPTO. Losleben earned degrees in electrical engineering and technology and management from George Washington and American universities, respectively.

More than three dozen program managers have served in IPTO since 1968. In 1984, IPTO had eight program officers, including the director, managing 38 programs in 15 areas. Considering the IPTO budget of $154 million, IPTO administration remained very lean. The programs had large budgets, and IPTO's projects at educational institutions were larger than those of most extramural basic research programs supported by other government agencies, such as NSF. IPTO program managers needed to have other abilities as well as technical competence. They had to be able to insist on major objectives and have the confidence in the contractor to carry out the objectives in a responsible and timely manner. DARPA and the DOD taught the young office directors and program managers management of programs of this size.

The program managers were usually participants in IPTO-sponsored projects before their arrival at IPTO. They came to IPTO with essentially the same philosophy as that held by the office directors and undertook their new duties at IPTO with enthusiasm [62]. They believed they were involved in a very significant undertaking, which meant much to computer science and engineering, the institutions associated with IPTO, and ultimately the defense of the nation.

Program Development and Interaction with the Research Community

Directors and project managers brought a substantial knowledge of computer science, and IPTO directors a broad view of computing to IPTO. For 18 of the 25 years covered in this article, the directors came from the Cambridge/Boston area. There, at MIT, Harvard, Lincoln and Draper laboratories, and the MITRE Corporation, many innovative computer projects had been pursued, including many for military systems. Their knowledge of research in computing proved invaluable in program development.

Licklider's early program represented his view of computing research needs and that of the Cambridge computing community. (See Table 2 for a summary of the early IPTO program categories, and Table 3 for a summary of the later categories.) Led by this vision, expressed in his "Man-Computer Symbiosis" paper, Licklider encouraged able researchers from Cambridge and elsewhere to propose projects and programs that would change the nature and style of computing. Licklider took substantial interest in Project MAC at MIT, which he initiated, and a project at SDC, which he inherited. He offered Robert Fano, first director of Project MAC, strong support. At SDC, however, he wrote critical reviews of results, took a hard line on renewal requests, sent in consultants to encourage changes, and refused to support some proposed activities [63].

TABLE 2. IPTO PROGRAM AREAS AND SPECIFIC EMPHASES (FY 1965 & FY 1971)

FY 1965	
Research into command and control processes, particularly man-machine interaction	Computer Languages
Advanced programming techniques	Timesharing
Advanced computer systems and their organizations as related to defense problems and computer usage	Advanced "software" techniques
FY 1971	
INFORMATION PROCESSING TECHNIQUES	DISTRIBUTED INFORMATION SYSTEMS
Automatic programming	Networks
Picture processing	ILLIAC IV
Intelligent systems	Climate Dynamics
Speech understanding	

TABLE 3. IPTO PROGRAM AREAS AND SPECIFIC EMPHASES (FY 1985)

INTELLIGENT SYSTEMS
- Image understanding
- Basic AI research
- Knowledge base processing
- Expert systems
- AI applications
- Distributed problem solving

MODERNIZATION
- Robotics technology
- Support software
- Computer resources

ADDCOMPE

AUTOMATION TECHNOLOGY
- VLSI architecture and design

NEW GENERATION SOFTWARE AND SYSTEMS
- Visual programming
- AI based software

SYSTEM AND NETWORK CONCEPTS
- User interface technology
- Advanced system concepts
- Adaptive networks

STRATEGIC C3 EXPERIMENT

SURVIVABLE NETWORKS
- Suran
- Multiple satellite
- Network security

VLSI FAST TURNAROUND
- Foundry development
- Foundry automation

INTEGRATED PACKET NETS
- European cooperation
- Wideband Net
- Network integration

DISTRIBUTED SENSOR NETS

SOFTWARE SYSTEMS
- Distributed C3 software
- Programming environments
- Distributed computing

STRATEGIC COMPUTING
- Machine architecture/software
- Generic AI software
- Infrastructure
- Applications

OTHER

The second source of program development came from the research community. Often Licklider and his successors welcomed proposals like that presented to Sutherland by the University of Utah's David C. Evans that led to substantial IPTO-supported R&D efforts in graphics. These close connections between the office and the research community have continued [64]. Among Licklider's first actions as IPTO director was a tour of the country's major computing centers. From this tour he identified and recruited researchers in new areas of interest to IPTO and learned what they could and would do [65]. Robert Taylor visited contract sites "once or twice a year, sometimes more often" [66]. Other government agencies have used site visits with varying frequency to stimulate programs. IPTO site visits, however, were more frequent and resulted in continuing evaluation of progress and staff, ideas for new programs, and influence of subsequent research at the site. At times the office director would visit a group alone; at other times he was accompanied by other IPTO staff or the DARPA director. In the 1960s, Licklider twice assembled a group of outside consultants for site visits to the System Development Corporation's facilities in California to broaden the SDC staff's horizons.

Programs also developed in various meetings of IPTO project research personnel, which began when Licklider sought advice informally:

> If I was going to be successful, I had to have some kind of system here. Maybe have one place interact with another, get these guys together frequently.... We would get our gang together, and there would be lots of discussion, and we would stay up late at night, and maybe drink a little alcohol and such. So I thought I had a plan at that level. I could talk about it to people at ARPA [67].

Taylor went further than assembling ad hoc groups of principal investigators (PIs) at professional society meetings. He called special meetings of the principal investigators and their research teams. PI meetings, as they were called, began in the mid-1960s, dropped off in the mid-1970s, resumed in the 1980s and continue today. Forty-six attended the January 1973 meeting, of whom six were from IPTO. Project leaders made 38 presentations about their projects and progress [68].

> I would ask... each principal investigator to get up and give an hour or two description of his project, of the sort... he'd like to hear from each of the others.... I think those meetings were really important. Through those meetings these people, all of whom were pretty bright, got to know one another better. I got them to argue with one another, which was very healthy, I think, and helpful to me because I would get insights about strengths or weaknesses that otherwise might be hidden from me. Through these we could look for opportunities where one group might be able to help another in working on some technical problem, or making some contact with some resource for some kind of supplier [69].

The entire group then intensely discussed research results. Today, however, the number of participants is in the hundreds and the PI meeting is more like a typical professional society meeting. "Participants complain that the earlier sense of give and take is no longer possible with such a large group" [70]. DARPA is experimenting with new structures for PI meetings to recover the "small" feel of the earlier meetings.

The development of the ARPANET exemplifies another use of the PI meetings. At the 1967 PI meeting, Roberts and the assembled researchers discussed the development of a plan for a networking project and established working groups to design a stan-

dardized communications protocol and specify network requirements. The working groups were helpful in bringing the first few nodes into operation within two years [71].

IPTO-organized study groups evaluated the state of a subfield, determined where substantial advances would be most advantageous, and suggested new program definitions, e.g., speech understanding in 1970 [72]. In the spring of 1970, Roberts assembled a study group led by Allen Newell "to consider the feasibility of developing a system that would recognize speech to perform some task" [73]. It crafted a five-year program to pursue speech research, evaluated the results of projects and prepared a follow-on report in 1976 calling for continued research. IPTO did not fund a follow-on until almost a decade later [74].

Directors and program managers consistently strived to interact with researchers sponsored by IPTO, and sought to have the researchers interact and disseminate research results to the computing community through meetings of various kinds. Researchers themselves, they strongly desired to aid the community in its work to achieve the IPTO mission, one designed and carried out by IPTO and the community and not somebody higher up in the DOD.

In the early 1970s, several changes in DOD affected DARPA. Many dominating themes of the 1960s dropped from DARPA's agenda. DARPA abandoned counterinsurgency research, and the Defender program, a program to study ballistic missile defense. In place of Defender, DARPA organized a new Strategic Technology program. "In essence, the door was closed on the original 'Presidential issues' that had been the foundation of DARPA's work for a decade. No comparable mandates on broad new issues were assigned to the Agency" [75]. DARPA's new assignments were in specific defense problem areas, with a new emphasis on joint service-DARPA projects. The Strategic Technology, Tactical Technology, and Information Processing offices became the core of the DARPA organizational structure, requiring a greater emphasis on application systems and attention to DOD needs rather than the needs of basic research only.

In the 1970s, command and control was still considered the key to "effective utilization" of the armed forces. DARPA directors sought "a synergistic relationship among computer science, communications, and information sciences" to advance the technology base [76]. IPTO program directors saw a need for basic research in areas such as intelligent systems, VLSI, and software technology to interpret images automatically, abstract text material, and develop advanced tools and techniques for engineering real-time microprocessor software and systems [77]. Here they continued to rely on the research community to design and implement programs.

Advanced network concepts for communications also required more research. For example, IPTO wished to extend the proven technology of the ARPANET to packet switching in a satellite communication environment, and to packet radio to provide a mobile, distributed and secure network. In addition, they sought teleconferencing and advanced automated message handling capabilities. This focus clearly addressed a DOD mission.

DARPA believed it necessary to develop an experimental system to evaluate new ideas for command and control technologies that emerged from IPTO research. To accomplish this they established "test beds," the goal of which was to allow the military to evaluate new technology: to "try-before-buy." Test beds would bring the work of the computer scientist, communications engineer, and information scientist together to achieve the synergy DARPA thought was lacking in the development of command and control systems. Another goal was to assess a "variety of competing technologies." Testing new technologies in a test bed would also provide user responses and further cooperation between IPTO and other DOD groups.

Kahn helped design specifications for what eventually became the ARPANET

DARPA stimulated work on faster, more complex semiconductor microprocessors that would allow the inclusion of more instructions in the integrated circuits. Furthermore, if the micron barrier in semiconductors could be breached, microprocessors could become even faster and more sophisticated. IPTO proposed a program to design advanced VLSI architectures to make possible integrated circuits that would far surpass existing silicon-based circuits for achieving high-data-rate signal processing. Components and major new systems employing these components would have to be designed and tested. In many ways, this area combined researcher interests with DOD concerns to the great advantage of both groups.

From 1974 to 1980, when this new approach was taking shape, new leaders with greater concern for near-term payoffs for the DOD from research assumed direction of DARPA. George Heilmeier pushed IPTO to be more mindful of the military applicability of research and exploratory development projects. He pushed test beds and experimental testing to determine the relevance of new ideas for use in military systems. His successors also insisted on military applicability. The later IPTO program bore the stamp of all these men and resulted in an expanded IPTO program. The elements of basic R&D remained but the program included ever more explicitly defense oriented projects. The insistence by DOD for development to help to increase the sophistication and speed of new military computing systems was a challenge IPTO was prepared to undertake.

DOD concerns about the standing of American high technology industry, especially the defense industry, and world trade in the 1980s led to programs for the quick transition of useful ideas from university research programs and IPTO test beds to industry. After the announcement by the Japanese of the *5th Generation* Computer Program in the early 1980s, Richard DeLauer, Deputy Secretary of Defense for Science and Technology, and Robert Cooper, DARPA Director, were among those who called for a new program to help maintain the United States position in computing, especially as it related to defense. Kahn and his colleagues in IPTO and other DARPA offices responded with the Strategic Computing Program (SC), which received Congressional funding in 1984: IPTO coupled university and test bed projects to defense industry programs, where many of them were pursued for specific applications.

In 1985, Saul Amarel identified several "exciting scientific/technological developments... that promise to accelerate further the impact of computing on defense and on our national economy." Networking and VLSI spawned several novel multiprocessor architectures that provided the high performance for research in vision, speech, complex symbolic processing, and large scientific problems. AI was starting to have a noticeable impact on many industrial and defense problems [78].

Conclusion

The IPTO program was a complex, highly interrelated set of activities. It included intelligent systems, advanced digital structures and network concepts, distributed information systems, advanced command, control and communications, and strategic computing and survivability. Over the 25 years of IPTO's history some parts of the program, such as intelligent systems, changed their projects but not their objective, that is, the search for more capable, flexible, intelligent, and interactive computer systems. The basic technology program continued research on the frontier of computing and added test beds and applications to the program to meet new needs. Beginning as a small DOD office with a calculated mission to make computing more useful in military command and control–Licklider's vision for IPTO–the program grew under his successors into a concern for computing as a national activity. This elevated IPTO to the world stage of computer development. IPTO directors envisioned a radically different future for computing, based on their knowledge of the research community and the interests of DARPA directors and higher-level administrators in the DOD.

IPTO directors emphasized ambitious technical objectives and nurtured the institutional framework for R&D in information processing resulting in some remarkable technical achievements. The information age grew out of their vision of an interactive computing world. IPTO gained a formidable reputation. Many outside observers are convinced that there is a special character in IPTO worthy of being emulated by other government agencies involved in the support of R&D [79]. The special character, they argue, comes from the capability of the IPTO directors to select technologies particularly ripe for development, their diplomatic facility in working with the research community, their skill in managing large contracts in a large program, and their standing in the research community. These men are seen as the antithesis of the government bureaucrat. The successful aspects of the IPTO program have contributed to an enlarged view of this special character and to the loyalty of a sizable group in the research community. The recent debate about organizing a civilian DARPA began because many believers in the efficacy of DARPA as promoter of R&D, and by inference IPTO, believe this special character can be replicated in a civilian agency. Creating a civilian DARPA in the current government climate of budget stringency and accountability, however, seems difficult if not impossible. The Congress is not in the mood to give any agent the freedom the IPTO directors possessed that made them so successful. Replicating IPTO's success, even in a technical area that is presently as immature as computing was in 1960, requires the same dedication and single-mindedness shown by Ruina, Fubini, Licklider, and their successors in the DOD. We need to define the new mission.

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[20] F. H. Tyaack, "Progress Report: Survey of the Information Sciences," IDA-IM-198, 23 May 1960, Contract No. SD-50, RG 330-74-107, Box 1, no folder label, National Archives Branch Depository, Suitland, Maryland, hereinafter cited as NABDS. The survey was done "mostly" in March and April 1960.
[21] "Message from the President of the United States Relative to Recommendations Relating to Our Defense Budget," *87th* Cong., *1st* Sess., March 28, 1961, *House Documents*, Document No. 123, p. 8.
[22] Institute for Defense Analyses, *Computers in Command and Control*, Technical Report Number 61-12, Nov. 1961.
[23] In fact, the work statement and research plan in the DARPA contract are identical to the 1960 SDC proposal for "Research into Information Processing for Command Systems," SDC Command-Control Research, *Proposal 184*, Nov. 1960, BR-L-31 SDC Command Control Research, System Development Corporation Series, Burroughs Corporation Records, CBI.
[24] Stuart Cooney, "Command Control Research and Development," *SDC Magazine*, Feb 5, 1962, System Development Corporation Series, Burroughs Corporation Records, CBI.
[25] Advanced Research Projects Agency, APC 307, Aug. 1961, "Command Control Research," RG 330-78-0013, Box 1, Folder: "Program Plans," NABDS.
[26] The ARPA office responsible for most of the computing research support has had several names during its short history. For a period in 1962 the office was called the Command and Control Program, but from 1963 to 1986 it was known as the Information Processing Techniques Office IPTO. The lineal continuation of IPTO was the Information Science and Technology Office ISTO organized in 1986. ISTO was reorganized in May 1991 into the Computing Systems Technology Office CSTO and the Software and Intelligent Systems Technology Office SISTO.
[27] David Allison made a similar assessment of the effect of individuals in his study of Navy R&D programs. According to Allison, Navy research programs in the 1950s and 1960s were guided by individuals, and the programs reflected the "initiative, advocacy, and entrepreneurship" of these individuals. He went further and noted that in the 1980s "programs are still defined primarily by the particular individuals involved in them and not by oversight by higher authority." D. K. Allison, "U. S. Navy Research and Development Since World War II," Merritt Roe Smith, ed., *Military Enterprise and Technological Change*, op. cit., p. 328.
[28] Karl L. Wildes, and Nilo A. Lindgren, *A Century of Electrical Engineering and Computer Science at MIT, 1882-1982*, Cambridge, Mass.: MIT Press, 1985; Leslie, *The Cold War and American Science*, op. cit.; Carroll W. Pursell, Jr., editor, *The Military-Industrial Complex*, New York: Harper and Row, 1972.
[29] A statement of the work proposed in this project is contained in a letter from Charles E. Hutchinson to Paul A. Dittman one of Licklider's co-workers on the project, Oct. 17, 1960, RG330-78-0085, Box 3, Folder: "Air Force," NABDS.
[30] J.C.R. Licklider to Charles E. Hutchinson, Nov. 30, 1960, RG 330-78-0085, Box 3, Folder: "Air Force," NABDS.
[31] J.C.R. Licklider interview with William Aspray and Arthur L. Norberg, Oct. 28, 1988, Charles Babbage Institute.
[32] J.C.R. Licklider, "Man-Computer Symbiosis," *IRE Transactions on Human Factors in Engineering, HFE-11* pp. 4-11, March 1960.
[33] Charles M. Herzfeld interview with Arthur L. Norberg, Aug. 6, 1990, Charles Babbage Institute. Herzfeld recalled that Licklider was around the DOD discussing computing problems at least by the time Herzfeld arrived in Sept. 1961. We know Licklider was not there in July 1962. A routing slip attached to an Air Force Memorandum ["Command and Control, Revision #1] dated July 18, 1962 has a handwritten note "Hold for Lick." Note and memorandum in RG 330-78-0013, Box 1, NABDS. Additionally, an SDC memo noted that Licklider had been involved in their contract since May 1962. P.D. Greenberg to T.C. Rowan, "SDC History," July 9, 1964, Memorandum No. M-14368, Folder: "PDG Archives," System Development Corporation Series, Burroughs Corporation Records, CBI.
[34] J.C.R. Licklider to Charles Hutchinson, June 13, 1962, RG 330-78-0085, Box 3, no folder label, NABDS.
[35] J.C.R. Licklider to Charles Hutchinson, June 13, 1962, RG 330-78-0085, Box 3, no folder label, NABDS.
[36] Robert W. Taylor interview with William Aspray, Feb. 28, 1989, Charles Babbage Institute.
[37] Ibid.
[38] Howard Rheingold, *Tools For Thought: The People and Ideas Behind the Next Computer Revolution*, New York: Simon & Schuster, 1985, p. 149.
[39] Ivan E. Sutherland interview with William Aspray, May 1, 1989, Charles Babbage Institute.
[40] Ibid.
[41] See especially the Herzfeld interview, CBI.
[42] Taylor interview, CBI.
[43] Ibid.
[44] Reinhold, *Tools for Thought...*, op. cit., passim.
[45] Such liaisons are often formed among federal agencies. In the 1980s these liaisons have taken on a more formal character as in the Federal Coordinating Council for Science, Engineering, and Technology FCCSET, which prepared a study of high-performance computing. Office of Science and Technology Policy, "The Federal High Performance Computing Program," Washington, DC, 1989. A number of people who were part of IPTO and its successor ISTO served on the subcommittee that generated this report.
[46] Sutherland interview, CBI.
[47] Taylor interview, CBI.
[48] Robert E. Kahn interview with William Aspray, March 22, 1989, Charles Babbage Institute.
[49] Lawrence G. Roberts interview with Arthur L. Norberg, April 4, 1989, Charles Babbage Institute; DARPA, Program Plan No. 439, "Graphic Control and Display of Computer Processes," March 1, 1965, RG 330-78-0013, Box 1, Folder: "Program Plans," NABDS.
[50] Roberts interview, CBI.
[51] Ibid.
[52] Allan G. Blue interview with William Aspray, June 12, 1989, Charles Babbage Institute.
[53] Patrick H. Winston interview with Arthur L. Norberg, April 18, 1990, Charles Babbage Institute.
[54] Kahn interview, CBI.
[55] Quotations taken from the Kahn interview, CBI.
[56] Kahn interview, CBI.
[57] Saul Amarel interview with Arthur L. Norberg, Oct. 5, 1989, Charles Babbage Institute.
[58] The appearance of a missionary attitude is not unusual at the beginning of a research field. Another example of this can be found in attitudes of the cyclotron engineers of the 1930s. For a discussion of cyclotroneering, see John L. Heilbron and Robert W. Seidel, *Lawrence and His Laboratory: A History of the Lawrence Berkeley Laboratory*, vol I, Berkeley, Calif.: University of California Press, 1990.
[59] This point was emphasized in virtually all CBI interviews with DARPA directors. See the interviews in CBI with Jack Ruina (interview with William Aspray, April 20, 1989), Charles Herzfeld, George H. Heilmeier (interview with Arthur L. Norberg, March 27, 1991), and Robert S. Cooper (interview with Arthur L. Norberg, Oct. 1993).
[60] Squires served for a time as director of CSTO, one of ISTO's successors.
[61] Simpson retired from the Air Force as a Lt. Colonel and Ohlander from the Navy as a Commander.
[62] This emerges from a reading of a number of the interviews with program managers and office directors. See Vinton G. Cerf interview with Judy E. O'Neill, April 24, 1990, Stephen Crocker interview with Judy E. O'Neill, Oct. 24, 1991, Robert E. Kahn interview with Judy E. O'Neill, April 24, 1990, Ronald B. Ohlander interview with Arthur L. Norberg, Sept. 25, 1989, Roberts interview, and Robert L. Simpson interview with Arthur L. Norberg, March 14, 1990, all Charles Babbage Institute.
[63] Licklider to Donald Drukey and Thomas Rowan, July 8, 1963, RG 330-69-A-4998, Box 3, Folder: "350-1: Licklider/Fredkin correspondence, July to December 1963," NABDS; RG 330-69-A-4998, Box 2, Folder: "Information International, Inc.," NABDS.
[64] Michael L. Dertouzos interview with Arthur L. Norberg, April 20, 1989, Charles Babbage Institute.
[65] See the Licklider interview, passim, CBI.
[66] Licklider interview, CBI; Taylor interview, CBI.
[67] Licklider interview, CBI.
[68] ARPA Contractors Meeting Briefing Book, Jan. 8-10, 1973, Keith Uncapher papers, CBI.
[69] Taylor interview, CBI.
[70] Dertouzos interview, CBI.
[71] L. G. Roberts, "Resource Sharing Computer Networks," *IEEE International Convention Digest*, pp. 326-327, March 1969; *The ARPANET Completion Report*, unpublished draft prepared by BBN, Sept. 9, 1977, pp. III-25-26; Roberts interview, CBI.
[72] Allen Newell et al., *Speech Understanding Systems: Final Report of a Study Group*, Amsterdam: North-Holland, 1973. The other members of the group were Jeffrey Barnett, SDC; James W. Forgie, Lincoln; Cordell Green, Stanford; Dennis Klatt, MIT; J.C.R. Licklider, MIT; John Munson, SRI; D. Raj Reddy, CMU; and William A. Woods, BBN.
[73] Allen Newell et al., op. cit.
[74] Allen Newell interview with Arthur L. Norberg, June 10-12, 1991, Charles Babbage Institute.
[75] Barber, *The Advanced Reseorch Projects Agency*, op. cit., p. I-12.
[76] "Statement submitted by Dr. George H. Heilmeier," Hearings before the Senate Subcommittee on Defense Appropriations, *Department of Defense Appropriations far Fiscal Year 1978, Part 5: Reseorch, Development, Test, and Evaluotion*, 95th Cong., 1st Sess., Feb. 4, 1977, pp. 44-172; see especially pp. 57-60.
[77] Ibid.
[78] Saul Amarel, "Issues and Themes in Information Science and Technology," Feb. 5, 1987. Provided by Saul Amarel.
[79] Two recent examples are Burton I. Edelson and Robert L. Stern, "The Operations of DARPA and its Utility as a Model for a Civilian ARPA," The Johns Hopkins Foreign Policy Institute, Nov. 1989, A background paper for the Carnegie Commission on Science, Technology and Government, and the Commission's report *Technalagy and Economic Performance: Organizing the Executive Bronch for a Stronger Notional Technolagy Base*, Sept. 1991, New York: Carnegie Commission on Science, Technology, and Government.

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